Industrial Mineral Background Paper 6

Rehabilitation of Sand and Gravel Pits for Fruit Production in Ontario

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Ministry of Natural Resources
Ontario

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Prepared for the Industrial Minerals Section, Mineral Resources Branch, Ontario Ministry of Natural Resources

by E.E. Mackintosh and M.K. Hoffman

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Rehabilitation of Sand and Gravel Pits for Fruit Production in Ontario

by E.E. Mackintosh[1] and M.K. Hoffman[2]

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Prepared for the Industrial Minerals Section, Mineral Resources Branch, Ontario Ministry of Natural Resources.

1.0 Background

In Ontario, concern over the wise management and stewardship of agricultural lands remains a major issue (Centre for Resources Development 1972, 1974). Where agricultural and aggregate resource lands overlap, the major concern is for a productive agricultural after-use following extraction. The concept of multiple-resource use has been used by members of the aggregate industry for some time. Numerous examples (Yundt and Augaitis 1979) are available throughout Ontario where mined sand and gravel lands have been restored to a wide variety of agricultural uses, recreational uses, housing developments, etc.

The concept of multiple-resource use, together with the known overlap between prime aggregate and agricultural lands, has been described in the publication "Agriculture and the Aggregate Industry" (Mackintosh and Mozuraitis 1982). This study deals with the extent of overlap between high quality sand and gravel lands and agriculture lands, an assessment of the success of sites rehabilitated to agriculture in Ontario, and a set of guidelines for the general rehabilitation of sand and gravel pits to an agricultural after-use.

More recently, the important role that specialty crops play in the agriculture-food industry in Ontario has been highlighted. Specialty crops, which include a range of vegetables and fruits, are grown on lands that have very specific climatic and soil requirements. Tender fruits such as peaches, cherries and grapes are even more specific in their requirements and are grown in only a few areas of the province. It is also known that prime aggregate deposits underlie some of these areas. Extraction of these aggregate resources without due attention to their proper rehabilitation could impair future production of these crops.

As a result of the continuing demand for aggregate and the revision to the Food Land Guidelines policy to include a provision regarding aggregate extraction in selected specialty crop areas, a further study was undertaken in the current rehabilitation series to address the specific needs of tender fruits. This report focuses on steps that should be followed to ensure successful rehabilitation of mined sand and gravel lands back to tender fruit production. It also provides an evaluation of the success of several sites which have been rehabilitated for tender fruit production in Ontario.

2.0 Government Regulations and Policy

2.1 THE PLANNING ACT

The principal legislation governing the use of land in Ontario is the *Planning Act* which delegates the prime responsibility for land use planning to municipalities. Official plans and zoning by-laws are the chief planning tools of the municipalities. Various Provincial Government policies, including the Mineral Aggregate Resource Planning Policy (see section 2.3 of this report) and Food Land Guidelines (see 2.4), must be considered in the preparation of municipal official plans and zoning by-laws. Aggregate extraction and rehabilitation must be addressed.

Municipal planning approval must be obtained before a licence to establish or operate a pit or quarry can be issued under the *Pits and Quarries Control Act* (see 2.2). Information on the rehabilitation of a proposed pit or quarry is usually required by the municipality before approval can be obtained. This information must also be shown on the site plan for a licence.

2.2 PITS AND QUARRIES CONTROL ACT

This legislation (Province of Ontario 1972) regulates and controls the operation of pits and quarries and requires their rehabilitation through a licencing process. Much of southern Ontario and areas around Sudbury and Sault Ste. Marie are now designated under this Act. A licence is required to establish or operate a pit or quarry on private land in these areas. A licence cannot be issued where the location is in contravention of a municipal official plan or zoning by-law (see 2.1). The licence (or permit) must be accompanied by a site plan which describes the detailed operations of the pit or quarry as well as the rehabilitation of the site.

The site plan is the mechanism whereby the Act ensures that some form of rehabilitation will take place. In addition, the aggregate producer is required to pay a rehabilitation security deposit of $0.08 per tonne of aggregate removed from the pit or quarry up to a maximum of $3000 per hectare requiring rehabilitation. The money is refundable as rehabilitation is undertaken. The producer can claim for the costs of rehabilitation provided the money on deposit is not reduced to less than $1000 for each hectare requiring rehabilitation. When final rehabilitation of the site has been completed, all the remaining money in the security deposit is refunded.

The Ontario Ministry of Natural Resources is also undertaking an Aggregate Resources Inventory Program (e.g. OGS 1982). Reports published under this program include a detailed inventory of sand and gravel and bedrock resources by municipality with mapping at 1:50,000 scale. It is being undertaken for all municipalities designated under the *Pits and Quarries Control Act*, as well as some additional areas where deemed warranted.

In addition, all deposits are assigned to one of three categories on the basis of aggregate quantity and quality.

The Aggregate Resources Inventory information is a valuable planning tool and is used by municipalities, the aggregate industry and the Ministry of Natural Resources in their various planning exercises.

2.3 MINERAL AGGREGATE RESOURCE PLANNING POLICY

The Mineral Aggregate Resource Planning Policy ("MARP" Policy) is a provincial government policy dealing with planning of aggregate resources and their extraction. Its purpose is to ensure continued availability of aggregates at reasonable cost, while minimizing adverse effects of aggregate extraction on the natural and social environments. It is implemented primarily through municipal official plans and zoning by-laws.

The Policy requires that the planning process should provide for the protection of pits and quarries and aggre-

Figure 1. *Specialty crop lands require a unique combination of soil and climate for commercial production.*

gate resource lands, provide a process to consider applications for new aggregate operations, and address the rehabilitation of extractive sites.

The MARP Policy is to become a Policy Statement under the *Planning Act*.

2.4 FOOD LAND GUIDELINES

The Food Land Guidelines (Province of Ontario 1978) is a provincial government policy that deals with the preservation of agricultural lands. The policy sets out a process to define and identify agricultural lands, establish priority ratings on these lands, and develop land use designations and supporting policies for Official Plans.

The guidelines, first published in 1978, are currently under review to be issued as a Food Land Preservation Policy Statement under the revised *Planning Act*. Meanwhile Section 3.12 of the Food Land Guidelines has been deleted and replaced by Section 3.16 which specifically addresses the issue of mineral aggregate extraction in selected specialty crop land areas of the province (OMAF 1983).

Specialty crop lands (Figure 1) are determined by a unique combination of climatic and/or soil conditions which supply the specific needs of crops such as fruits and vegetables (Dube 1981). Because of their limited extent, these lands play a crucial role in the agriculture-food industry of Ontario.

The revised guidelines recognize that some of these areas also have a resource potential for sand and gravel extraction. Five areas have been identified (Figures 2,3,4,5) and include parts of the Niagara Region, the Blenheim area in Kent County, the Leamington and Harrow areas in Essex County, and the Meaford-Thornbury area in Grey County. Mineral aggregate extraction is permitted in these areas if documentation is provided to reasonably show that:

(a) the site can be rehabilitated for agriculture to allow specialty crop production on the same area and at the same level of productivity, and

(b) there will be no effect on climate or micro climate on which the area may be dependent for specialty crop production.

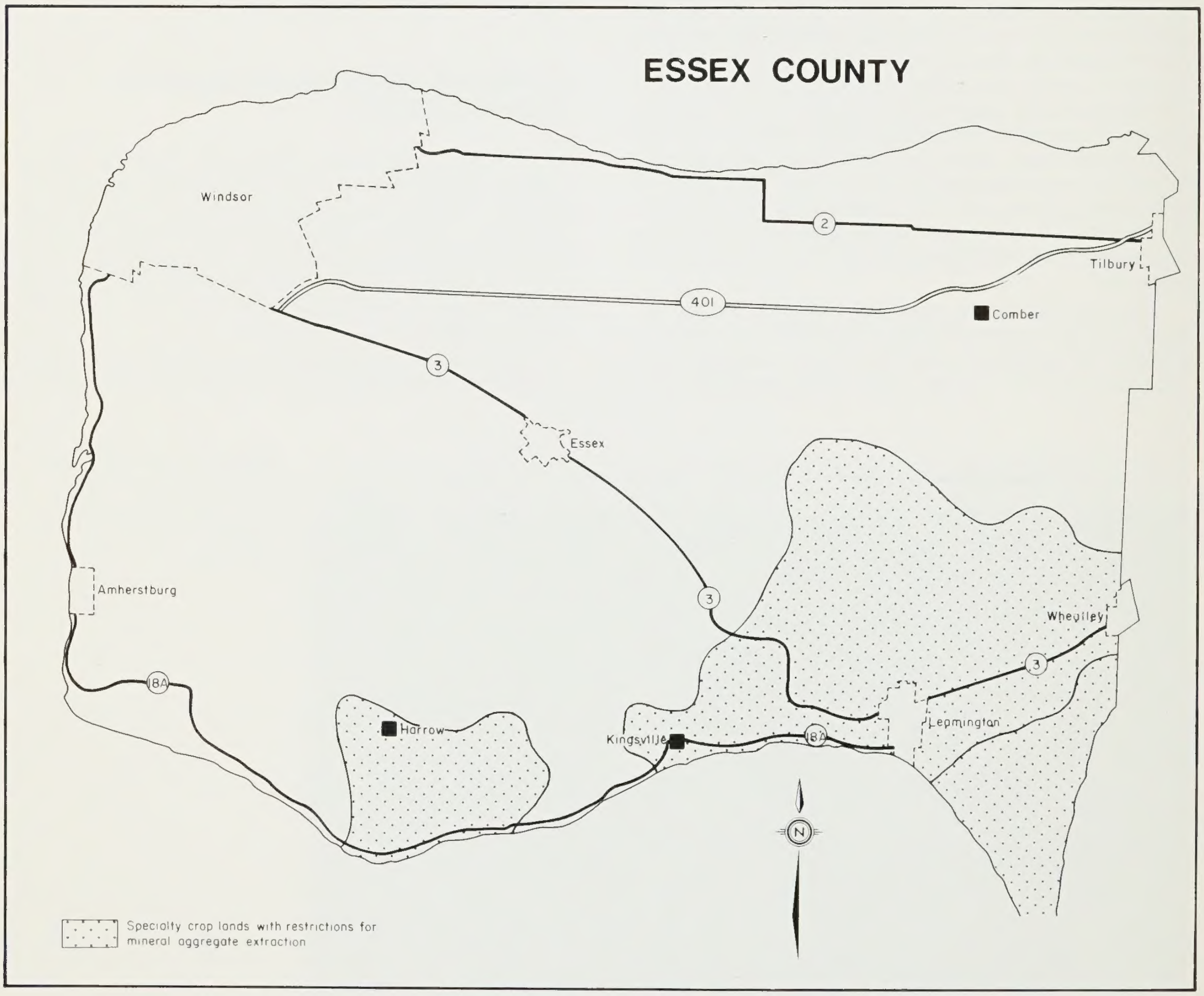

Figure 2. *Mineral aggregate extraction on specialty crop lands in Essex County (Province of Ontario 1982).*

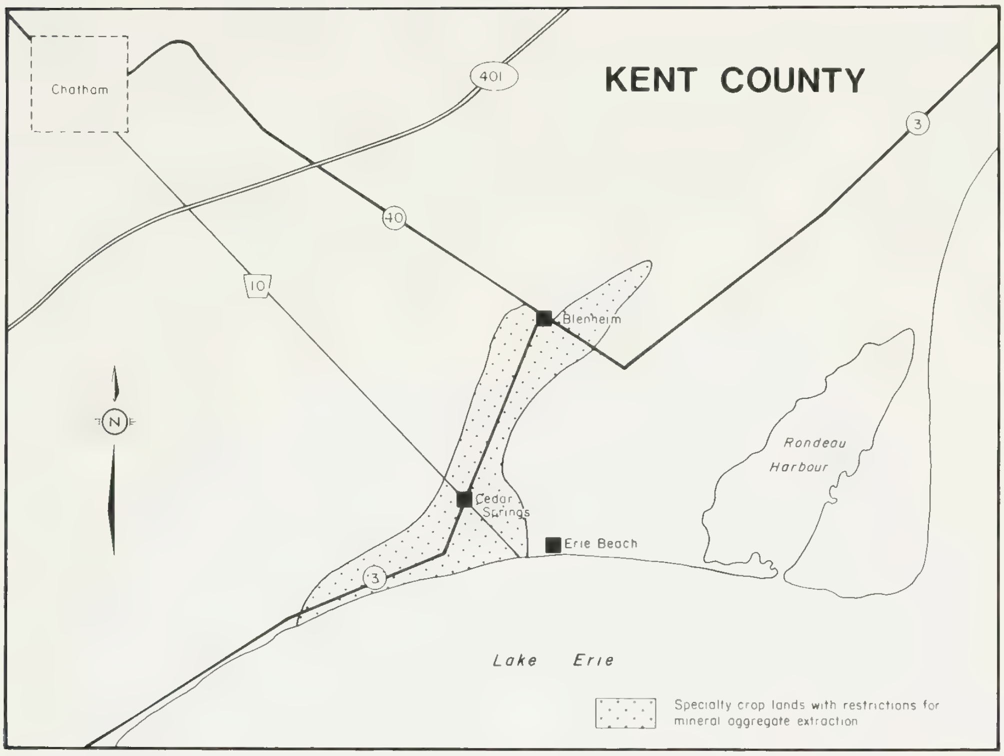

Figure 3. *Mineral aggregate extraction on specialty crop lands in Kent County (Province of Ontario 1982).*

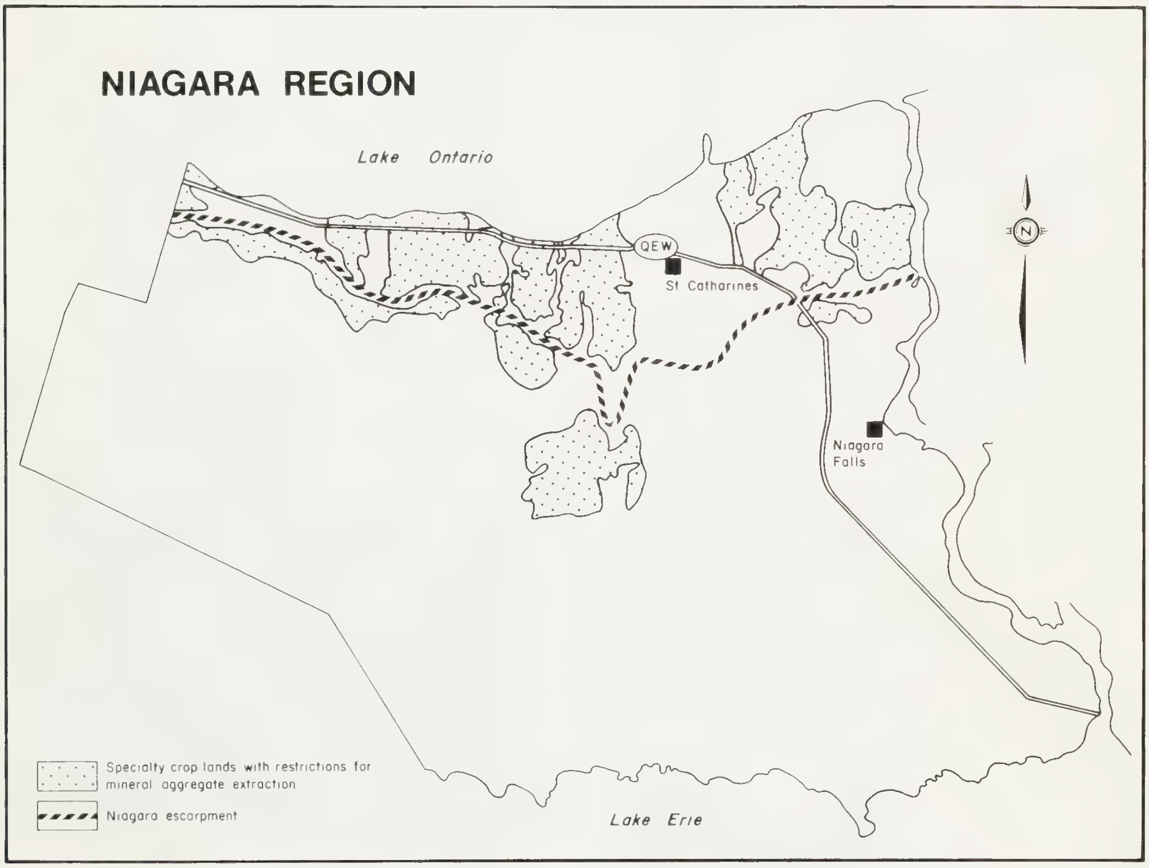

Figure 4. *Mineral aggregate extraction on specialty crop lands in Niagara Region (Province of Ontario 1982).*

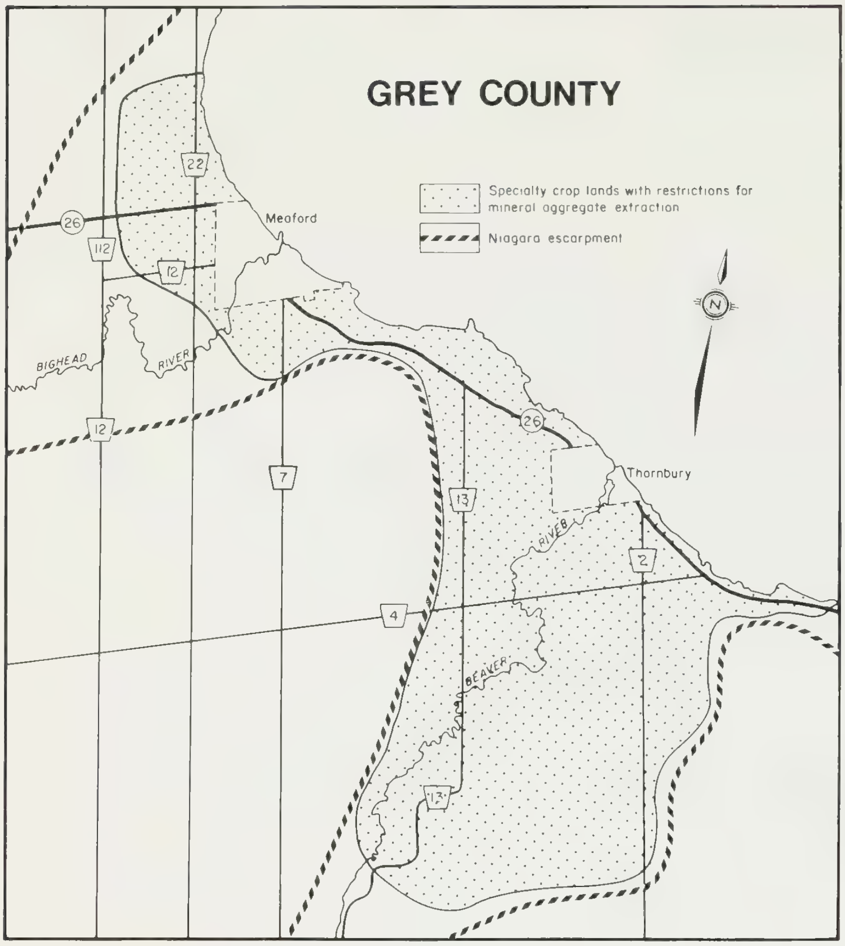

Figure 5. *Mineral aggregate extraction on specialty crop lands in Grey County (Province of Ontario 1982).*

3.0 Lessons from Rehabilitation Elsewhere

Extensive areas of mined sand and gravel lands have been rehabilitated back to specialty crop production in California, as well as in parts of Europe, particularly Great Britain. The degree of success of rehabilitation projects varies depending upon site conditions, the guidelines established for rehabilitation, post-rehabilitation management, and most important, implementation, that is the transfer of knowledge to the machine operators who are undertaking the work.

3.1 CALIFORNIA

Many of the sand and gravel deposits found in California are alluvial in origin. They sometimes contain up to 6 to 9 m (20 to 30 feet) of overburden. Large areas were stripped in order to extract the sand and gravel and there are now extensive areas of rehabilitated lands (Figure 6) in California. Peach trees originally grew on many of the visited sites which are now being replanted with almonds and to a lesser extent, walnuts, because of their lower labour costs and greater returns on investment. As well, extracted sand and gravel areas are commonly reclaimed for grape production.

The rehabilitated areas range from a few hectares to over 100 hectares. Although yield records are not kept on a systematic basis, farmers on good rehabilitated lands are obtaining yields equivalent to pre-extraction levels while those located on poorly rehabilitated lands are obtaining substantially less than average yields.

Figure 6. *California has rehabilitated large areas of mined aggregate lands for specialty crop production. Almond orchards are a common end-use.*

In California, a major problem encountered in rehabilitating sand and gravel pits is subsidence and land levelling. Practically all orchard lands in the area are equipped with underground irrigation systems and require perfectly level land for operation. Almond trees, as an example, cannot withstand ponding of surface water around their roots, and even minor subsidence in the order of a few centimetres creates severe management problems. This is usually overcome by growing a forage crop for two to four years following rehabilitation in order to allow settling to reach an equilibrium.

Where grapes are being grown on the rehabilitated land, it is common to contour the area to an uneven slope for cold air drainage and surface water drainage. A minimum soil depth of approximately 1.2 m over the ground water table is provided on sites that are being rehabilitated for almond production.

Subsoil ripping to a depth of 1.2-1.5 m is a common practice on rehabilitated lands that are being used for specialty crop production. Areas are commonly double-ripped at an angle with the tines approximately 1.5-1.8 m apart. This tends to relieve soil compaction and improves infiltration and movement of water through the soil.

3.2 EUROPE

In Great Britain, major deposits of sand and gravel are located along river terraces. These sites are mined and then the excavation is usually refilled with landfill material, particularly building rubble. These sites are not being rehabilitated for tender fruit production for climatic reasons; however, significant areas are being used for vegetable production.

Common problems encountered in rehabilitating mined aggregate lands in Great Britain include subsidence which is related to the underlain landfill materials, soil compaction which reduces root penetration and water infiltration, and in some instances, the lack of topsoil.

Again, success of rehabilitation projects is closely related to the quality of the rehabilitation plan and the ease with which the plan is translated into practical operation.

Joint agricultural land restoration experiments are being undertaken by the British government and industry at the Papercourt and Bush farms (Department of the Environment *et al.* 1977, 1982). These long term experimental sites are providing invaluable information on a wide range of restoration problems. As a result of the study a number of procedures have been recommended and implemented. These include: progressive rehabilitation; wet weather shut-down policy; double soil stripping (where appropriate); soil ripping; and soil organic matter amendments and fertilization

Aggregate rehabilitation in the Netherlands follows a specific process and requires site planning. Most importantly, the work is approached from the standpoint of an integrated plan for the total aggregate deposit. Such an approach assures consistency in an overall plan for an aggregate area. This overall planning approach for a total resource area is not presently applied in southern Ontario.

4.0 Climatic and Soil Requirements for Tender Fruit Production

4.1 GENERAL CLIMATIC REQUIREMENTS AND COLD AIR DRAINAGE

In southern Ontario, tender fruits such as peaches, cherries and grapes are being grown at their northern limit of survival. To ensure commercial production, advantage has to be taken of proximity to water bodies such as the Great Lakes and sloping land. Cold air drainage is an important consideration in the production of certain cold-sensitive crops in Ontario. Particular advantage of this air drainage phenomenon has been taken on favourable lands (e.g. Figure 7) in the vicinity of the lower Great Lakes. Proper air drainage will ameliorate cold damage to overwintering plants, to spring blossoms, or to fall fruit.

Peach, sweet cherry and vinifera or hybrid grapes are the most sensitive fruit crops, followed in descending order of sensitivity by sour cherry and apricot, pear and plum, and apple. Damage to dormant buds of peach and grape occurs with temperatures of about -25°C or colder, while peach wood is severely damaged at -30°C. Peach flowers are damaged by spring temperatures of -3°C. Apricot trees are more cold-hardy than peach, but bloom earlier and are, therefore, more susceptible to late spring frost. Pear production is also limited by frost at blossom time and by severe winter temperatures, although well-hardened wood and buds will survive down to -30°C. Dormant wood and buds of apple can tolerate -35°C when properly cold-hardened, but spring buds and small fruit may be damaged at -2°C.

These climatic limitations effectively restrict large scale commercial production of tender fruits in Ontario to the Niagara Peninsula and the Leamington-Harrow areas along Lake Erie.

The most anomalously cold temperatures of fall, winter or spring, usually occur during nights with clear skies and very light or calm winds. Under clear skies, the crop loses a great deal of heat by invisible, infra-red radiation that escapes to space. If present, clouds would intercept a portion of this energy and re-radiate it back to the ground, but on a clear night radiant heat losses proceed unchecked and the near-surface air layers cool quickly. A temperature inversion forms, where the coldest air lies at the crop level and temperatures increase upwards for some distance.

The inducement of cold air drainage on a site will ameliorate cold damage. The downslope flow will cause stirring in the near-surface air layers, transporting heat from the warmer reservoir aloft toward the surface. This is similar to the creation of low level mixing with wind machines or aircraft. However, in the case of air drainage it is the natural force of gravity that is being harnessed to move the air, so good design demands that impediments to the flow are minimized as much as possible.

4.2 SOIL CHARACTERISTICS

Soil is defined as a medium for the growth of plants. It anchors the roots of the plant and furnishes the plant with nutrients, water, and oxygen for growth and reproduction. Tender fruit crops have different soil requirements than many other agricultural crops. In general, tender fruits require deep, well drained, sandy soils. Indeed, many of the soils which are considered as prime lands for tender fruit production are often considered as rather poor lands for general, arable agricultural crops. The following characteristics are desirable for optimum tender fruit production:

Topsoil depth:	variable
Total soil depth:	minimum 1.2 m
Texture:	gravelly sandy loam to sandy loam
Aeration:	40-60% porosity
Drainage:	rapidly to well drained
Depth to water table:	absolute minimum 1.2 m

Figure 7. *Tender fruits are particularly sensitive to frost damage. Orchards, such as this one, must have good cold air drainage which is determined by slope.*

Stoniness: variable; usually determined by equipment problems
Relief: may vary from site to site; depends on cold air drainage and extent of farm mechanization

The above characteristics are affected by a range of soil properties including: texture, structure, compaction, available soil water storage, drainage, stoniness and depth. These properties, together with relief, are explained in more detail in the sections that follow.

Topsoil, Subsoil and Overburden

Three distinctive zones of soils (Figure 8) are recognized in rehabilitation of sand and gravel lands: topsoil, subsoil, and overburden. Topsoil and subsoil are the most important layers for plant growth. The terms are defined as follows:

Figure 8. *Soil can be divided into topsoil, subsoil and overburden. In the photo, topsoil is the dark layer at the top; subsoil is the lighter coloured layer under the topsoil; and overburden is the dark layer under the subsoil. The bottom of the pit consists of the sand and gravel parent material. (Scale in centimetres.)*

Topsoil: This is the uppermost zone of the soil and is recognized by the dark brown or black colour which is caused by the accumulation of organic matter. On arable agricultural lands, topsoil is normally stripped to the depth of cultivation which is about 15-30 cm, and stockpiled for rehabilitation.

The key component of topsoil is organic matter. It promotes the development of good soil structure and improves soil strength, two characteristics which are crucial for soils to withstand mechanical pressure from agricultural machinery. As well, organic matter improves the water holding capacity of soil and supplies nutrients for plant growth.

Subsoil: This is the layer that occurs immediately beneath the topsoil and may extend down to a depth of 1 m or more. Because subsoil is often well structured, it will contain numerous plant roots and during summer drought periods, plants may obtain much of their moisture requirements from this level.

The subsoil is low in organic matter but may contain accumulations of clay-sized material. On tender fruit lands, it is not uncommon for the subsoil layer to be missing.

Overburden: The term overburden is restricted to all material lying between the subsoil and the workable sand and gravel deposit. Again, many sand and gravel deposits in Ontario are not overlain by overburden materials. The material below the subsoil may be undesirable for agronomic purposes and should be handled separately in the stripping and restoration process. Since tender fruits require good drainage, some coarse textured, sandy materials may be quite suitable for rehabilitation purposes. In many of the kame moraine gravel deposits, it is not uncommon for the base of the pit to be composed of pure sand. In these instances, this sand may provide an acceptable substitute subsoil for the production of tender fruit crops.

Soil Texture

The classification of mineral particles into gravel, sand, silt and clay is done on an arbitrary size division. In agriculture, the most commonly used size criteria are: gravel 75 to 2 mm, sand 2 to 0.05 mm, silt 0.05 to 0.002 mm, and clay less than 0.002 mm diameter (CSSC 1978). The proportion of sand, silt and clay in a sample determines its texture and terms such as sandy loam, loam, or clay are used to describe the different proportions.

The chemical and physical properties of soils are closely related to soil texture. For instance, soils with a high sand and gravel content are porous, hold little water and drain well. In contrast, a high clay content is the major factor contributing to shrinking, swelling, stickiness, and often, poor drainage in soil.

The soils of most tender fruit land are coarse textured in nature and tend to be composed of gravelly or sandy textured soils. They are often very porous with poor water holding qualities and in many instances, are excessively drained. These soils, therefore, are often droughty but are preferred for tender fruit production for these very qualities.

Soil texture is not normally altered by agricultural practices and should not be confused with soil structure which can regularly be changed by mechanical forces.

Soil Structure

Soil structure refers to the physical arrangement of mineral and organic particles into aggregates, granulars, peds or clods of different sizes and shapes. Structure is strictly a field term describing the overall aggregation and arrangement of soil particles.

Soil texture is an important factor in determining soil structure but it is the latter condition that significantly influences water movement, aeration, bulk density and porosity. Indeed, the physical changes to soil that are caused by man — cultivation, drainage, stripping and stockpiling — are structural rather than textural (see Figure 9).

The main agents responsible for binding the individual soil particles together are clay, decomposed organic materials, and plant roots. The most important of these agents is organic matter which is why the preservation of topsoil is so important in an agricultural rehabilitation program.

Standardized terms for describing soil structure are outlined in the Ontario Institute of Pedology publication "Field Manual for Describing Soils" (Belisle 1980).

Figure 9. *Vehicular traffic affects soil structure. This photo shows how compaction by vehicle tires can adversely alter soil structure.*

Soil Compaction

One of the more important characteristics related to texture and structure is the general configuration of pore spaces (or voids) in soil.

In coarse textured soils, pore space is largely determined by texture. As texture becomes progressively finer, structure exerts a greater influence on the nature of the soil pores. Ideally, a soil should contain 50 to 60% pore volume to allow adequate entry and movement of air and water through the soil. The degree of soil compaction determines the amount and size of soil pores.

Bulk density is used to describe the degree of soil compaction and is a measure of the weight of dry soil per unit volume expressed as grams per cubic centimetre (g/cm^3). Ideally, a soil should have a bulk density in the range of 1.0-1.4 g/cm^3. It is known for example that bulk densities in excess of 1.6 g/cm^3 in coarse textured soils will reduce crop yields for most agricultural crops. In contrast, a bulk density of 1.4-1.5 in a clay soil can cause a reduction in crop yield. Heavy vehicular traffic can compact soils severely and bulk densities in excess of 1.8-2.0 g/cm^3 are not uncommon on pit floors.

Porosity of soils is computed from bulk density (Db) and particle density (Dp) measurements. A particle density of 2.65 g/cm^3 is often used to calculate porosity in the equation:

$$\text{Porosity (\%)} = (1\text{-Db/Dp})100$$

The yields of most agricultural crops are reduced significantly when the pore volume falls below 35-40%.

At excessively high bulk densities (or low porosity), the roots of most plants will not penetrate the soil and this effectively reduces the volume of soil available to the plant for the extraction of soil water, air and nutrients.

Available Soil Water Storage

Available soil water storage is a measure of the amount of water available in the soil for plant growth and is directly related to soil texture. The available soil water storage on a volumetric basis can vary as follows:

Clay 5%
Clay loam 10%
Silt loam 18%
Sandy loam 12%
Sand 4%

Most tender fruit crops grow best on rapidly drained, coarse textured gravelly or sandy soils and consequently, the amount of water available to crops on these soils is limited. It is not uncommon, therefore, for tender fruit lands to require irrigation, as well as subsurface drainage. The limited capacity of coarse textured soils to store water means that the plant roots must be able to penetrate up to a metre or more into the soil to obtain adequate soil moisture reserves. Coarse, sandy soils, for example, may contain less than 1 cm available water holding capacity for 30 cm of soil depth.

Soil Drainage

Soil drainage is a general term which describes the amount of water found within the soil over a period of time. When water fills all the spaces or pores between the soil particles, the soil is said to be saturated. Air entry and movement is restricted under these conditions and the

soil may become devoid of oxygen, i.e. anaerobic. Plants must have oxygen to function properly. If the situation persists over a short period, their growth can be severely restricted.

Soils may become saturated for a number of reasons. Excess water that fills the soil pores normally moves vertically downward and its rate of movement is determined by soil texture and structure. Any abrupt changes in soil texture or structure can impede downward movement of water and cause saturation and/or horizontal movement of water to occur. Compacted layers created by heavy equipment or the presence of hard pan also cause similar problems.

The level of the underlying water table can also cause soil wetness. In low lying areas, the level of water table is often within the plant root zone. This effectively reduces soil depth.

The amount of time that excess water remains within the plant root zone is used as a criterion to determine soil drainage class. The duration of time that a soil remains saturated increases from well drained soils through imperfectly, poorly and very poorly drained soils. Under field conditions, soil drainage class is assessed visually by such things as soil color and structure.

Most tender fruit crops require an absolute minimum 1.2 m of soil overlying the soil water table. Many poorly and very poorly drained soils are unsuitable for tender fruit production even if the site is artificially drained by open ditches or tile drains. Indeed, it is not uncommon to have excessively and well drained, coarse textured soils underdrained with tiles for the production of tender fruit.

Soil Depth

In the production of agricultural crops, soil depth usually refers to the effective depth of soil which permits entry of plant roots to sustain their growth. Root growth can be restricted by compacted layers of soil, bedrock, indurated pans caused by cementing agents, waterlogged conditions, toxic chemicals or by consolidated subsoils. The following definitions are commonly used in Ontario soil surveys with respect to rooting zones overlying bedrock:

Very shallow	less than 20 cm
Shallow	20-50 cm
Moderately shallow	50-100 cm
Deep	greater than 100 cm

A decrease in soil depth reduces effective volume from which plants can extract nutrients and soil water.

Stoniness

Stoniness is a common problem associated with soils overlying sand and gravel deposits. The presence of stones has two effects on agricultural land. First, in mechanized farming, the presence of excessive amounts of stone hinders cultivation, seedbed preparation, and at times, may cause damage to farm equipment. Secondly, as the stone content increases, the volume of soil available from which plant roots can extract water and nutrients decreases.[7]

Post-rehabilitation management programs will, therefore, often require stone removal. The quality of land can be improved by stone picking operations.

Relief

The principal components of relief are elevation, slope and exposure or direction of slope. The primary influence of relief is through its effects upon water and air drainage. It is important that the rehabilitated land surface is graded to ensure adequate drainage of water. A gradient (slope) of 2-5% is desirable for proper development of microdrainage channels for surface runoff and drainage. Slopes of at least 1% or more are required to provide for adequate cold air drainage. Mechanical operations on orchard lands generally limit the maximum slope to 12% (8.3:1), but soil erosion problems may preclude the use of slopes as steep as this. Similarly, mechanical harvesting of grapes requires land with slopes of no more than approximately 6%.

5.0 Observations on Rehabilitation of Tender Fruit Lands in Ontario

A study of the rehabilitation of former sand or gravel pits to tender fruit production has been undertaken in southern Ontario. Although not a common practice, some former pits (Figure 10) have been returned to fruit crop production with good results. These sites were inspected in the field and the farmer/operator interviewed to ascertain farm management, yields and rehabilitation history. The main points of the study methodology and results follow. More detailed results of the work can be obtained from the Ministry of Natural Resources.

5.1 STUDY APPROACH

During the spring and summer of 1984, sites were visited to generally view blossoms, fruit formation and yield. At the same time, detailed notes concerning health of the fruit trees, relative amount of blossom, relative yields, soil characteristics, farm management, special methods, and problems in rehabilitation success were taken with help from the farmer.

5.2 EXTENT AND EVALUATION OF REHABILITATED SITES

A total of 12 orchards and vineyards had been planted in former gravel pits. On all of these sites extraction was commenced prior to the revision to the Food Land Guidelines regarding mineral aggregate extraction.

Five of the sites were planted to peaches, cherries (Figure 11) or grapes (Figure 12), while seven were planted to apples. All of the orchards or vineyards were small in size, ranging from 0.5 to 7 hectares. In some instances only a few rows of a crop had been grown.

Normally, the success of orchard rehabilitation is judged on the basis of yield taken over the lifespan of the orchard. However, due to the young age of most sites and the lack of yield data, success was measured by observations of tree survival and growth rate, amount of blossom and fruit, and incidence of disease.

In all cases except one, where the apple orchard has been abandoned as a result of ownership change and on the advice of horticulturalists, rehabilitation has been a success. Much of the success resulted from sound management practices (e.g. Figure 13). These include: general fertilization and in some cases, fertilization according to soil test or leaf tissue analyses; staking new trees; wrapping and/or painting tree trunks; pruning programs; and pesticide applications, usually according to the Ontario Ministry of Agriculture and Food phone line information (OMAF 1982).

Some farms had additional management practices. For example, one farmer applied pit-run materials (unprocessed pit material) around the base of the trees to reduce soil moisture loss. In other instances, trickle irrigation (Cline 1978) was used.

None of the farms had information on pre- or post-excavation yield levels of fruit trees of similar age, variety and rootstock. However, rehabilitated orchard lands

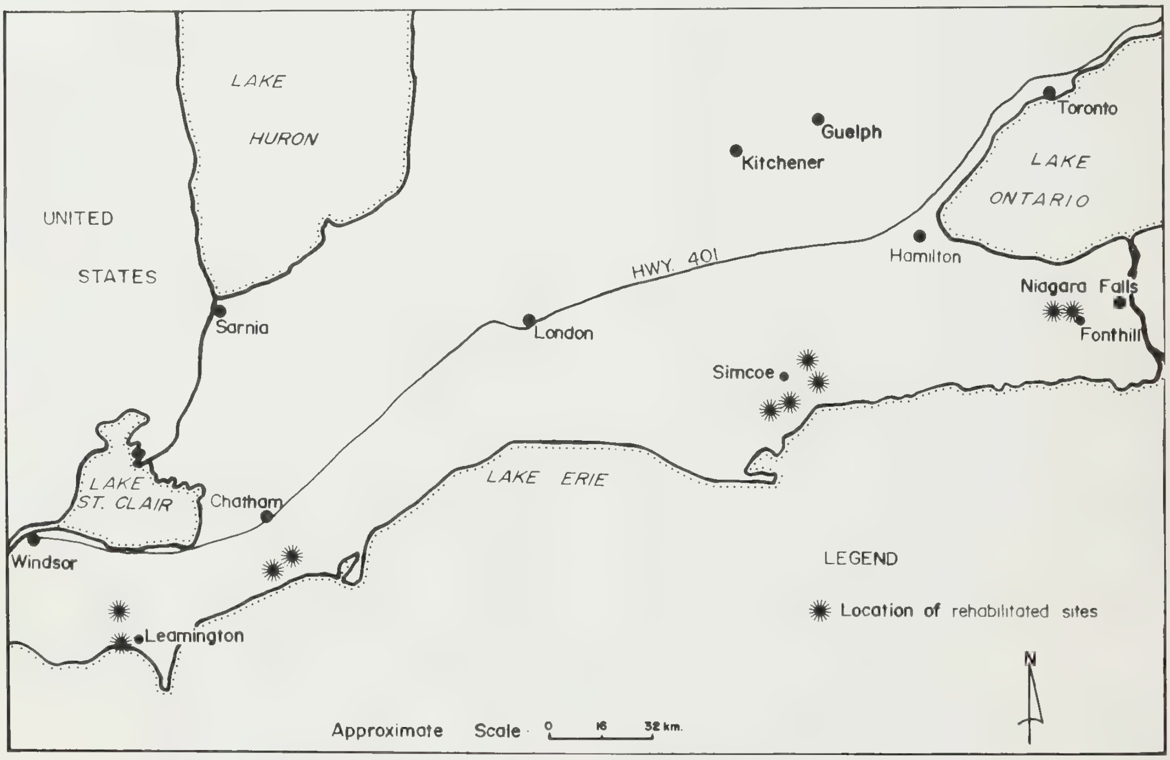

Figure 10. Location of rehabilitated sites in the study area.

Figure 11. *This cherry orchard, located in the Fonthill area, is an example of mined sand and gravel lands being rehabilitated to tree fruit production in Ontario.*

Figure 12. *These grapes are cultivated on land which was used for sand and gravel extraction and subsequently rehabilitated. The vineyard is located near Leamington.*

Figure 13. *Rehabilitation includes good farm management practices. Trickle irrigation, trunk wrapping and tree staking will increase the survival and production of young fruit trees.*

showed yield variations similar to those normally found in young orchards. Where trees were not allowed to produce fruit, that is, blossoms were removed, tree health and blossom number was similar to that found in adjacent orchards unaffected by gravel excavation.

5.3 PROBLEMS ENCOUNTERED IN REHABILITATION

Some problems were encountered by farmers during the rehabilitation process but these can usually be avoided by following the steps outlined in Section 6. Generally, rehabilitation on the sites studied has taken more time and money than would have been the case if the sites had been preplanned for rehabilitation to fruit production after extraction. This is because of problems encountered when preparing the land for fruit production.

On some of the sites, topsoil had not been fully stripped or had not been separated and used properly in site rehabilitation. On only two of the sites was topsoil fully stripped and returned. In both cases the removal and replacement was supervised by the farmer. In the remaining sites, portions of the topsoil had been sold. Where remaining topsoil resources were scarce, the materials were used in the manner which most benefitted the trees. For example, topsoil was used around the base of fruit trees or within the soil pit dug for the tree root-stock. Organic amendments such as straw or manure were also used to improve the quality of the topsoil.

Slope angle and ground level on rehabilitated lands had been changed. In all instances, land levels were significantly lower than before excavation; that is, no land fill schemes had been employed on any of the sites. On one site, land levels were maintained more closely with original height because a siltation pond was used. Slopes were all steep (greater than 30%) at the old pit face. Where trees were planted, slopes varied from nearly level (approximately 2%) to gentle (approximately 6%). In two cases, slopes were reduced from those existing before extraction, making farm management easier.

Due to the small size of the rehabilitated pits studied, a relatively large proportion of many of the sites was occupied by steep pit slopes (e.g. Figure 14). This resulted in a loss of land suitable for agricultural production and in some instances, created areas with poor cold air drainage.

Soil compaction was evident in some orchards (Figure 15). Only four of the twelve sites visited had used subsoilers or soil ripping equipment. Most compaction resulted in visible drainage problems and poor tree growth. In two of the four sites, treatment with a subsoiler occurred after the trees had been planted.

In none of the sites was soil stoniness sufficiently high to interfere with cultivation. However, some sites had very gravelly materials which reduce soil moisture retention.

Soil/water relationships varied markedly from site to site. Excess water required tile drainage and/or surface treatment such as contouring. Excess water resulted from compaction, a water table near the surface or from the use of fine textured subsoil materials. In other instances droughtiness had to be treated by use of irrigation. In several cases, the loss of a subsoil horizon with relatively more clay-sized particles has resulted in excessive drainage and poor moisture retention.

The subsoil horizon helps to keep soil moisture in the profile. However, the specific effect of this horizon loss could not be ascertained because the new dwarf rootstocks were, in most farmers' opinion, more susceptible to drought-induced injury. Thus, experience with losses for the old tree planting could not be compared to young dwarf trees found on rehabilitated land.

Figure 14. *Costly soil erosion problems can result from inadequate soil stabilization and bare, steep slopes.*

External Factors Affecting Rehabilitation

Other factors in addition to the climate and soil characteristics of the site may also affect rehabilitation success.

For example, surrounding land-uses can affect the production of good food crops. Since the rehabilitated land is usually low lying, surface waters from surrounding lands often flow onto the former pit area. This sometimes increases wetness on the site or results in the transfer of soils or other materials to the site. On one property, grapes were planted adjacent to a sanitary landfill where surface waters and trash from the landfill flowed onto the vineyard.

Another vineyard was located adjacent to a railway track. Preservatives such as creosote or pentachlorophenol have been used on railway ties, and some of these preservatives may have moved in surface waters which flow onto the lower rehabilitated lands. Control or direction of water flow away from the vineyards may be advisable. On some landscapes, railway embankments can also act as cold air dams.

On a narrow beach line ridge near Blenheim, the piecemeal mining of small portions of the deposit has resulted in loss of the aggregate resource on the slope areas at the edges of the former pits, as well as producing steep slopes unsuitable for agricultural production. The number and arrangement of the pits also make maintenance of cold air drainage more difficult.

Effects of Government Regulation on Rehabilitation

Legislation also affects the way in which sites are rehabilitated. Existing legislation (Province of Ontario 1972) allows for the use of a "short form" site plan as part of an application for a licence to establish or operate a pit or quarry producing less than 15,000 tonnes per year. This method is appropriate from a cost and general resource management viewpoint. However, short form site plans do not aid in the prediction of rehabilitation success for tender fruit crops. Specific data on ground water levels, surface and subsurface water movement, stoniness, topsoil depth, compaction treatment, topsoil and subsoil stripping need to be considered. Therefore, full detailed rehabilitation plans should be required for all tender fruit lands subject to aggregate mining.

Not only does the plan need to be accurately formulated, it needs to be enforced to ensure that the steps required for fruit land rehabilitation are followed. The most successful sites viewed in the field had rehabilitation supervised by the farmers who would be using the land for fruit production. Pit operators could benefit by hiring a farmer to aid them during rehabilitation.

All the farmers interviewed indicated that costs for fruit land rehabilitation were high relative to other crops. As well, these high costs did not include the full cost of the farmers' time. In light of this, consideration might be given to a review of rehabilitation security requirements for rehabilitation to fruit land. Publications produced by the Economics Branch of the Ontario Ministry of Agriculture and Food outline the costs for establishment and maintenance of orchards and vineyards. Pit operators should calculate these additional costs when determining the economic viability of extraction in fruit lands.

5.4 SUMMARY

In Ontario former sand and gravel pits have been successfully rehabilitated for the production of fruit based on observation of twelve rehabilitated orchards or vineyards.

The success of the rehabilitation depends on maintaining a minimum standard of physical conditions at the site, i.e. adequate topsoil and subsoil depth, good drainage and an adequate rooting medium. After these standards are met, fruit production depends on the manager adopting and implementing an adequate post-rehabilitation management program. As well, the site rehabilitation plans should have the flexibility to overcome problems such as lack of topsoil, stoniness, poor soil drainage, inadequate cold air drainage and land use conflicts with adjacent properties.

Figure 15. *Rehabilitated pits may have soil drainage problems. In this orchard, subsoiling of a former haul road would improve water infiltration by reducing soil compaction.*

6.0 Steps to Successful Rehabilitation

A number of steps are recognized as prerequisites for successful rehabilitation to tender fruit land. These are outlined in the subsequent paragraphs and in Figure 16.

6.1 PRE-PLANNING

(Step 1, Figure 16)

The variability in soil materials on existing or potentially active fruit land and the specific needs of these specialty crops result in the need for preplanning in pit rehabilitation. Each of the following seven sections (6.2 through to 6.8) should be addressed before extraction begins.

The *Pits and Quarries Control Act* requires that a site plan be prepared as part of an application for a licence. This plan must outline the existing site conditions, the method and staging of operations, and the proposed rehabilitation of the site.

Starting with the existing conditions (Province of Ontario 1972), the following site specific information should be gathered:

(i) topsoil, subsoil and overburden characteristics such as organic matter content, stoniness, structure, texture (CSSC 1978);

(ii) interpret (i) to determine soil capability (Figure 17) for agriculture for common field crops and specialty crops (DREE 1969; Ecologistics *et al.* 1984; Ontario Ministry of Agriculture and Food, Soil Capability Map Series);

(iii) past and present land use on and off the site;

(iv) crop yields;

(v) hydrogeology of the site, especially depth to the water table and the fluctuations in that depth seasonally and yearly;

(vi) subsurface water quality;

(vii) surface water drainage pattern;

(viii) surface water quality for water bodies on or adjacent to the site;

(ix) geology of the site including characteristics of the aggregate deposit.

The collection of these data will require a detailed site investigation and report. All of the data will serve as a benchmark against which the feasibility and success of the rehabilitation program can be determined.

Preplanning must outline **what** is to be affected, **where** it will be affected, **how long** it will be affected, and **what will be done** to minimize these effects during the extraction process.

6.2 LAND USE AND LANDSCAPE

A description of present and past land use activities is required within the zone of influence of the proposed pit. Data should include:

(i) The kinds of crops grown in the adjacent fields. Changes in cropping practices over the past ten to twenty years should be documented.

(ii) How the land has been designated within the Official Plan. What kinds of changes have occurred in that designation during the past ten to twenty years.

(iii) A description of restrictions which result from that Official Plan designation; that is, regulations that are outlined in the Zoning By-law.

Landscape features need to be considered in the formation of a site plan.

(i) What is the present relief or topography of the area, and how will the post-extraction topography affect cold air drainage when the site has been rehabilitated?

(ii) Will the proposed landscape contain plant materials which present problems for other specialty crop uses in the surrounding areas - for example, will plant materials used on berms or during the rehabilitation process serve as seed sources for plants viewed by adjacent landowners as weeds or pests?

6.3 PROGRESSIVE REHABILITATION

Progressive rehabilitation is the continual reclamation of mined land to a productive after-use as extraction proceeds on the site. In contrast to rehabilitation which is commenced only after all extraction has ceased, progressive rehabilitation has many benefits:

(i) the amount of land taken out of agricultural production at any one time is minimized;

(ii) the extraction area is minimized and therefore, the potential conflict with surrounding uses is reduced;

(iii) the annual payment paid by the aggregate producer into the rehabilitation security deposit is minimized;

(iv) soil materials are regraded and stabilized quickly, thereby reducing erosion problems and soil deterioration;

(v) an early assessment of the success of rehabilitation and an early identification of any problems will improve subsequent rehabilitation efforts.

The phasing and methods of progressive rehabilitation for tender fruit production should be detailed on the site plan.

6.4 STRIPPING AND STOCKPILING

(Steps 2 and 3, Figure 16)

Each layer of soil material, that is, topsoil, subsoil and overburden, should be stripped and stockpiled separately. The stripping should be completed under dry conditions to minimize soil mixing and compaction. Stockpiles should be immediately treated for erosion protection. A good cover of vegetation will normally provide adequate protection. Under some circumstances other stabilization methods may be required.

The soil survey completed during the preplanning stage will show the mean depth of the different soil layers and where they are found on the site. A site inspector familiar with the soil layers can help the soil-moving operators to minimize mixing of the different layers.

The conservation of topsoil is very important to successful rehabilitation. Every possible amount of this material should be saved and the total volume of saved topsoil calculated. From the calculated volume, the depth of an even cover of topsoil over the area, similar to pre-excavation levels, can be determined.

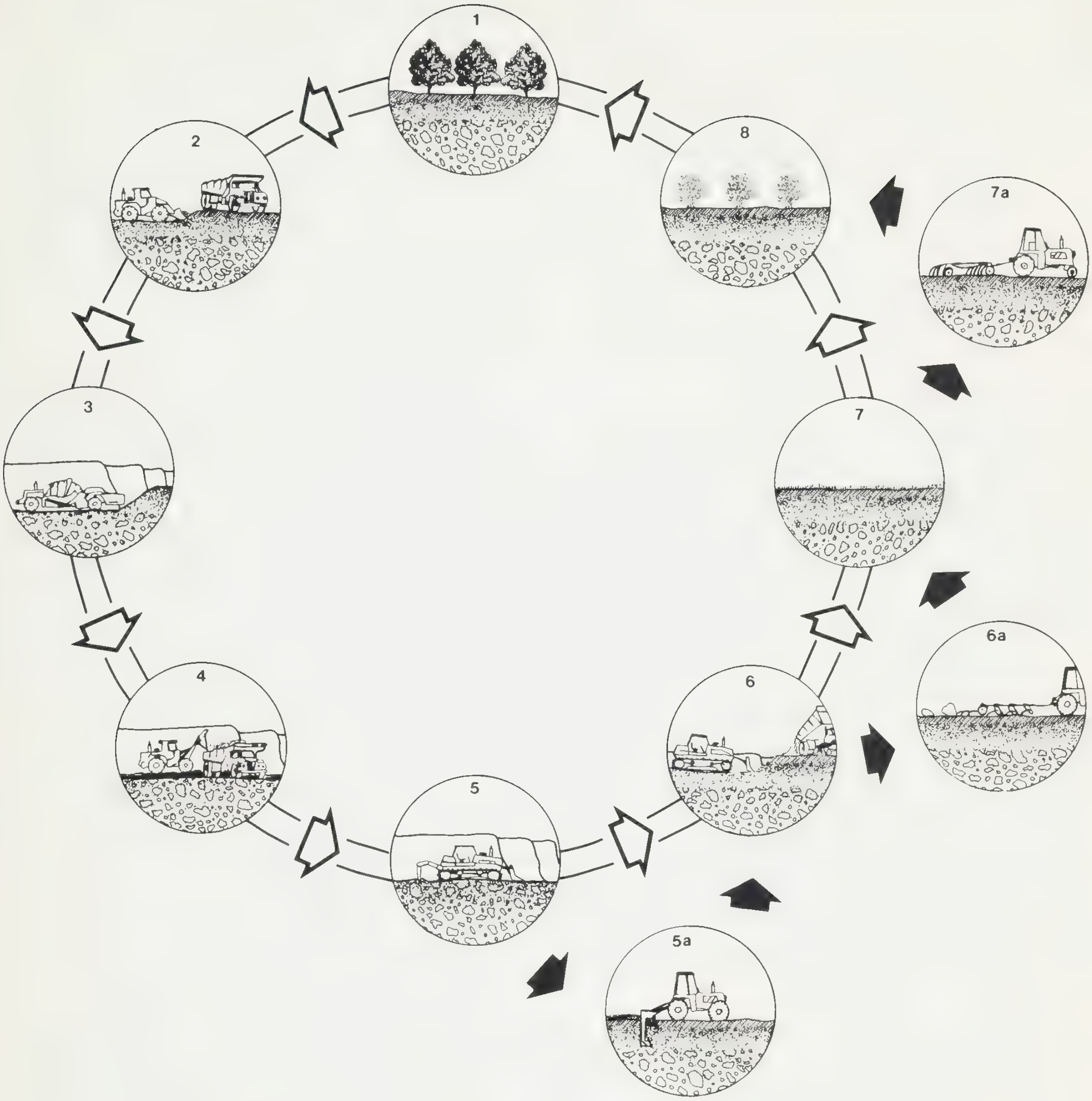

Figure 16. *The stages in rehabilitation of mined sand and gravel pits to tender fruit production.*

1. Preparation and planning.
2. Strip topsoil and subsoil and store separately.
3. Strip and store overburden.
4. Extraction.
5. Grading and contouring for cold air drainage.

5a. Ripping may be required.

6. Replace overburden, subsoil and topsoil.

6a. Chisel plow and stone pick, if neccessary.

7. Establish a legume/forage cover for 3-4 years.

7a. Plow under forage, deep till and stone pick when required.

8. Replant to orchards or vineyards.

6.5 GRADING AND RE-CONTOURING THE PIT FLOOR

(Step 5, Figure 16)

In the operational phase of sand and gravel pits, the pit floor often contains remnant piles of poor quality material, localized depressional areas where water can accumulate and a topography which may trap air and water onsite. To restore these lands to tender fruit production, the rehabilitation plan must contain provisions for grading and re-contouring the pit floor to provide adequate cold air and surface water drainage offsite. As well, the grading program should address slope needs for mechanized harvesting of tender fruits.

Cold Air Drainage Requirements

Cold air near the ground oozes downhill like a viscous liquid, and is retarded by any obstacles in its path. An excellent small-scale analogy would be to observe the flow of molasses over a plaster model of the terrain. As an aid to eliminating these obstacles, several desirable design principles should be adopted, as follows:

1. Minimize obstacles to the downslope flow. Since the flow is occurring close to the ground, obstacles include even short barriers such as hedges, walls, raised roadways or railroad embankments. There is, for example, clear evidence on infra-red photographs taken in the Niagara Peninsula (Stewart *et al.* 1977) that cold air blockage occurs at railroad embankments, the Queen Elizabeth Way, and buildings, thus restricting air drainage from the Niagara Escarpment toward Lake Ontario.

Figure 17. *Land has been mapped into one of seven different capability classes using the Canada Land Inventory, Soil Capability for Agriculture Classification. Class 1 has no limitations for common field crop production whereas Class 7 has no potential for crop production. Subclasses define the limitations for growing commercial crops. In this photo limitations include steep topography (t), wetness (w) and inundation - flooding (i).*

Figure 18. *Cold air drainage is essential on tender fruit lands. Closed drainage depressions can create frost pockets.*

2. Eliminate or avoid any depressions where cold air can pond (Figure 18) on the site. Even subtle changes in elevation are very important. Several examples are reported in the literature of situations where "a few tenths of a metre" change in elevation give rise to substantial temperature differences.

3. Avoid horizontal constrictions along the flow pathway. Any narrowing of the cold air spillway by natural or man-made structures will slow the flow upslope from the constriction and subsequently reduce the beneficial effects of the air drainage. Wherever a valley narrows, the flow of cold air is dammed up (Geiger 1965).

In addition to eliminating blockages, hollows and constrictions, the pit floor should be graded to a minimum slope to produce tangible benefits from air drainage. A flow velocity of 1 m/s (2.2 mph) is the minimum required to induce any significant convective heat transport (Crawford 1965). The flow velocity is related to the length and the angle of the slope, and to the difference in temperature between the top and bottom of the slope and can be calculated from an empirical relation.

Theoretical slope angle and slope length estimated from the empirical relationship, using a flow velocity of 1 m/s, represent an absolute minimum for ensuring beneficial air flow. Slope angle and slope length that generate theoretical velocities larger than 1 m/s should be used wherever possible. Irrespective of these results, a slope of more than 1% should always be used. Slopes of less than 6% are desirable for mechanized harvesting of grapes and erosion control, whereas mechanical harvesting of orchards is usually restricted to slopes less than 12%.

Surface Water Drainage

Re-contouring should eliminate small pockets of closed drainage systems (depressional areas) where water tends to accumulate and cause water-logged conditions. The overall design must identify an outlet for surface run-off from the site and provide for an adequate hydraulic gradient.

The hydraulic gradient is determined by the depth of mining, i.e. the elevation of worked pit floor. Unless the site plans reflect this concern for drainage in the original design, needless expense could be incurred in earth moving, such as stripping and/or filling, in order to meet final grade.

Slopes of the regraded pit floor should not exceed 5% so as to control soil erosion losses.

Backslopes of excavated pits commonly have 3:1 or 2:1 slopes (Figure 19) which are excessive from the standpoint of mechanized farming. For orchard purposes, slopes in the range of 10:1 are generally satisfactory for mechanized harvesting. The desirability of grading backslopes to 10:1 must be assessed against site characteristics. The trade-offs include: the economic loss of marketable sand and gravel; and the relative size of the backslope area to the area of the pit floor. As the area of the excavated pit increases, the proportion of the backslope decreases. If the objective is to maximize the amount of good agricultural rehabilitated lands, steeper slopes may be preferred.

Reshaping of the pit floor should also provide for large, regularly shaped fields on the post-extraction landscape to facilitate mechanized farming.

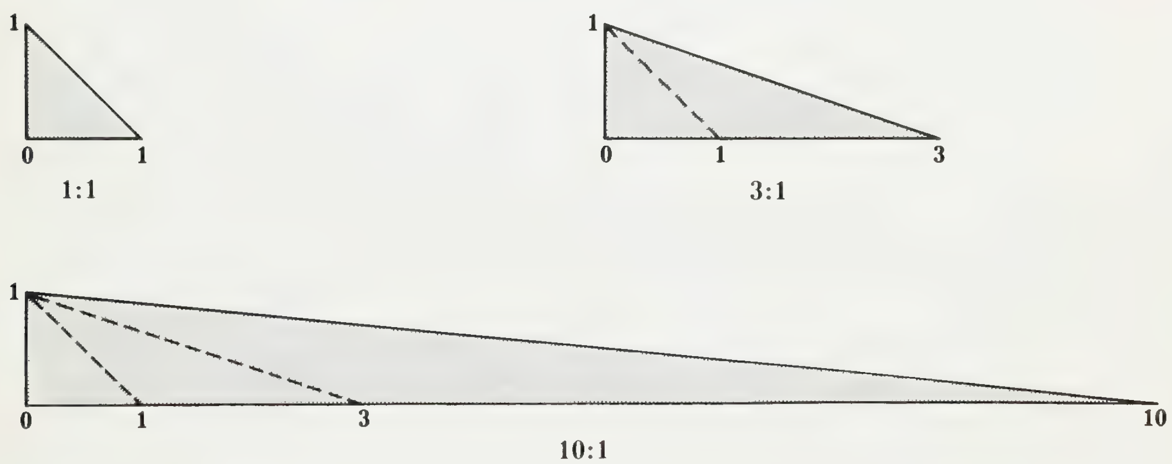

Figure 19. *Slope gradients.*

1:1 — Maximum final pit slope allowed under Section 8.1, 8.2, Ontario Regulation RR784/80, *Pits and Quarries Control Act.*

3:1 — Generally considered maximum gradient for safe access up and down slope.

10:1 — Satisfactory for agricultural use and erosion control.

6.6 DEPTH TO GROUND WATER TABLES

The amount of overburden remaining over the mean high ground water level is a major factor determining the practicability of rehabilitating tender fruit lands. An absolute minimum of 1.2 m of soil free of a ground water table is required for fruit tree production. Two metres is recommended for optimum production. The most obvious solution is to restrict the depth of mining but this is not always feasible.

Excavating below water table level eliminates agricultural rehabilitation unless special precautionary measures are taken. These measures include the use of inert fill materials to raise the elevation of the pit floor or the installation of a drainage system designed to lower water table levels through the use of interceptor drains and tile drains. Such measures may not be economically feasible, especially as water depth increases.

6.7 SOIL COMPACTION AND RIPPING

(Steps 5a and 6a, Figure 16)

Mining activities related to the sand and gravel industry involve the use of heavy earth moving equipment such as motorized scrapers, front-end loaders, or bulldozers. Compaction of the pit floor occurs during periods of active mining, as well as during re-application of topsoil/subsoil/overburden.

Amelioration of surface and subsoil compaction is required in rehabilitation of former pits. The pit floors of some sites will require ripping (Figure 20) in order to eliminate natural soil cementation which leads to "hard pan" development at depth. These "hard pans" may be exposed as a result of mining. They are impermeable to plant roots and must be broken up for successful site rehabilitation.

During rehabilitation, compaction can be minimized by working under dry conditions and using alternative types of earth-moving equipment which exert pressures less than 1-2 kg/cm^2. This can be accomplished by utilizing wide tracked crawler tractors and smaller machinery equipped with rubber tires.

Amelioration of soil compaction is accomplished by mechanical means. Surface soil compaction, less than 30 cm deep, can be eliminated by repeated operations with a chisel plough. Where soil compaction exceeds 30 cm in depth, agricultural subsoilers or rippers should be used. Rippers mounted on the back of crawler tractors are preferred on sites where materials below the pit floor are stony (Figure 21).

6.8 POST-REHABILITATION MANAGEMENT

(Steps 6a through 8, Figure 16)

After soil materials have been graded, layered and stabilized, additional work is required, over time, to restore soil to its original productivity level. This rehabilitation includes improvement of soil organic matter content, restoration of soil structure and therefore, re-establishment of soil voids which allow for the movement of water, oxygen and plant nutrients.

The post-rehabilitation management scheme should consist of the following:

(i) Levelling — in some areas land may subside. In these areas land should be levelled to ensure that surface water and/or cold air drainage is maintained.

(ii) Stone picking — cultivation practices and frost action may bring stones to the surface. These stones should be removed (Figure 22).

(iii) Organic matter — the addition of green manure and/or animal manure will enhance organic matter levels in the soil. These materials should be incorporated into the soil surface through cultivation.

(iv) Fertilization — in addition to organic matter amendments, other chemical fertilizers will be required for crop growth. Before fertilizer is added, a soil test should be completed. This test will indicate what the current fertility status of the soil is and will indicate the type and rate of fertilizer required. Different rates will be required depending on the crop being grown.

(v) Timing — the use of legumes (Figure 23) for at least three years before the planting of tender fruit crops is rec-

Figure 20. *Subsoiling or ripping reduces soil compaction and aids in soil water infiltration and movement.*

ommended. In this way, soil structure will be restored before trees are planted.

(vi) Cultivation — special cultivation practices may be required to relieve compaction or remove stones. These practices may have to be completed more than once as monitoring of the site reveals specific problem areas.

(vii) Monitoring — the success of rehabilitation should be observed throughout the site. Changes in soil character, relief, fertility or in plant growth may signal the need for modifications to the post-rehabilitation plan. The monitoring should be carried out by a qualified agrologist.

(viii) Irrigation and/or Tile Drainage — fruit crops are sensitive to high or low water levels. Therefore, water control is essential. Either or both irrigation and tile drainage may be necessary in rehabilitated sites. The sensitivity of young dwarf fruit trees to drought suggests that irrigation may be necessary. In some sites, tile drainage has been necessary because of the proximity of the water table to the new soil surface.

(ix) General Management — fruit trees have specific management requirements such as pruning and pesticide treatment. Gravel pit operators may wish to retain a local farmer to supervise these specific crop management practices.

Figure 21. *Soil materials found in rehabilitated sand and gravel pits are often gravelly or stony.*

Figure 22. *Stone picking may be required before soils are suitable for fruit production.*

Figure 23. *Rehabilitation often requires the planting and subsequent plowing down of legume/forage crops. In this photo, portions of the land are still in legumes and grasses while other areas, rehabilitated earlier, are in orchards.*

Figure 24. *Pits can be rehabilitated progressively. The orchard in the centre of the photograph will be bearing fruit before extraction of the unused area is complete.*

7.0 Summary

Many areas of specialty crop lands found in southern Ontario coincide with lands underlain by sand and gravel deposits. These lands require specific treatment if they are to be rehabilitated for fruit land production after aggregate extraction. Such rehabilitation has occurred within Ontario and in other parts of the world, particularly, California.

In Ontario, twelve rehabilitated orchard and vineyard sites were reviewed and assessed. In the absence of pre- and post-rehabilitation yield data, success of rehabilitation was judged on the basis of blossom set, incidence of disease and survival rates in comparison to adjacent control orchards. Using these criteria, eleven of the twelve sites had been rehabilitated to a satisfactory standard.

Several problems were identified during the assessment of site rehabilitation. These problems centre on the soil resource and include soil compaction, inadequate soil depth, inadequate topsoil, steep slopes and stoniness. Land use conflicts have also been identified between rehabilitated lands and adjacent land uses.

Problems of site rehabilitation for tender fruit production can be minimized by following an eight-step rehabilitation process. This will not only improve the likelihood of successful rehabilitation but it also speeds up the planning approval and pit licensing process. The steps include: pre-planning; land use planning; progressive rehabilitation (Figure 24); soil stripping and stockpiling; grading and recontouring the pit floor; maintenance of a minimum soil depth to ground water tables; soil compaction and ripping; and a post-rehabilitation management plan.

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